48/6

THOUGHTS

ON THE

MEANS of IMPROVING

WATCHES,

And more particularly thoſe

For the USE of the SEA.

Partly deduced from REASON, and partly from the OBSERVATION of EFFECTS attributed to particular Cauſes.

By THOMAS MUDGE.

LONDON:
PRINTED IN THE YEAR 1765.

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BETWEEN two and three Years ago an Act paſſed for granting to Mr. HARRISON an immediate Reward of 5000 *l.* on making a full Diſcovery of the Principles and Conſtruction of his Watch for the aſcertaining the Longitude of a Ship at Sea, and explaining the ſame to certain Perſons therein named. As, by a Summons I received, I unexpectedly found myſelf nominated to be one of them, it occurred to me, that, if I ever intended to advance any Thing which I apprehended neceſſary to the Improvement of Watchmaking as my own, it was prudent to take ſome Method to aſcertain its being ſo before his Diſcovery took Place; otherwiſe, I ſuppoſed, I ſhould on any ſuch Occaſion be treated as a Plagiary, if *my* Thoughts on the Subject ſhould fall in with *his*; a Circumſtance by no Means improbable, where two Perſons, if they have a Genius fitted to their Subject, are in Purſuit of the ſame Thing. I therefore ſat down a few Hours before the Time appointed for the Gentlemen to meet, and haſtily drew up a Paper containing ſome Thoughts upon that Subject, and lodged it with the Secretary of the Royal Society; but as the Diſcovery did not then take Place, and the next Meeting was appointed at ſuch a Diſtance of Time, as would admit of my writing it with a little more Correctneſs than could be expected from ſo haſty a Compoſition (and that of one but little uſed to write), I drew up the following Paper, and inſtead of lodging it with the Royal Society, ſubjected it immediately to the Peruſal of ſeveral Gentlemen of Character and Reputation for mechanical Knowledge, ſome of whom have taken Copies of it, and then withdrew my former Paper, which contains the Subſtance of this, but ſhorter. I now publiſh it, or rather print it, becauſe as ſeveral Copies are gone abroad, ſome of them may poſſibly find their Way into a News-paper, or Magazine, with more Faults than are my own, and there are enough of them without adding others; and that I may with Confidence be able to ſay, that it is printed from the original Copy, wrote between two and three Years ſince, which in a little Time I ſhould not be able to do, as the Papers (having paſſed through many Hands) are much worn, and but barely legible. I can with Truth ſay alſo, that its being wiſhed to be publiſhed by ſeveral Gentlemen, to whoſe mechanical Merit I pay a great Deference, was no little Inducement to my doing it. As Mr. HARRISON has now made his Diſcovery, and in Conſequence of it will ſoon receive his Reward, it cannot be ſuppoſed to be done with a View to prejudice him; indeed his mechanical Merit is too great to receive any Hurt by the Publication of any Thing upon that Subject by me, or any Body that I know. I ſhall only add farther, that as I was reſolved to print the Paper, *verbatim*, as originally wrote, I have added what appeared to me farther neceſſary, to make myſelf ſtill better underſtood, by way of Note, at the Bottom of the Page.

Oct. 25, 1765.

THOUGHTS

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THOUGHTS

ON THE

Means of Improving Watches.

THE ſimple Principles of all Watches are (I apprehend) the ſame, and perfect; the Errors found in them are therefore not Errors ariſing from the Principles, but from Imperfections inſeparable from all mechanic Operations. Theſe ſimple Principles I ſuppoſe to be nothing more, than that the ſame Force will always produce the ſame Quantity of Motion; and Quantity of Motion being compounded of Quantity of Matter and Velocity, the Quantity of Matter remaining the ſame, the Velocity will be the ſame, therefore a given Force will always produce the ſame Velocity in the ſame Time. Upon the above Principles, if a Maſs of inert Matter is ſuſpended on an Axis, and made a perfect Equilibrium, and a given Force exerted upon it in that Direction in which it is capable of being moved, it will produce a given Velocity in a given Time; the ſame Force exerted in contrary Directions alternately will produce a vibrating Motion, and the Force in each Vibration being the ſame, the Velocity will be the ſame. In order to conſtruct a Machine on theſe Principles to meaſure Time, it is neceſſary to contrive it ſo that the

Force exerted on the Ballance ſhall be in oppoſite Directions alternately; it is neceſſary alſo (to make it uſeful) that this Force ſhould act for a conſiderable Time (ſuppoſe twenty-four Hours) without being renewed by any external Agent: For that Purpoſe the Force muſt be encreaſed in the ſame Proportion, that the Time of one Vibration of the Ballance, bears to the Time the Watch is to go without renewing the Force. This Force ſo encreaſed is to be communicated to the Ballance through a Train of Wheels, whoſe Forces decreaſe in the ſame Proportion their Velocities increaſe, till the Force becomes equal to what was at firſt ſuppoſed to be immediately applied to the Ballance.

This was the Manner in which Watches were firſt made; but they were made in a very rude Manner, and, though very valuable and uſeful Machines, were found not to meaſure Time by any Means ſo accurately as might be expected from perfect Principles. The communicating this Force through a Train of Wheels was the Rock they ſplit on; it neceſſarily introduced a great many Errors ariſing from the Imperfections of the Mechaniſm, and the Friction that is unavoidable, though executed in the moſt perfect Manner; all which put together, produced a very *unequal* and *irregular*, inſtead of the ſuppoſed *equal* Force.

The firſt and moſt obvious Means of providing againſt theſe Errors, ſeems to be the Improving the Mechaniſm (for I have ſuppoſed it very rude), and I have ſeen ſome Watches of a later Date very well executed, without any other apparent Improvement; but the Advantages gained, by no Means anſwered the extraordinary Trouble. It was neceſſary therefore to look out for other Means of

Improvement ; and the firſt happy Thought
r that Purpoſe (as far as I can learn) was that
Dr. Hook and Mr. Huigens, in applying,
hat is commonly called (I ſuppoſe from the Re-
ularity it occaſioned) a Pendulum-Spring to the
allance, which was a great Step towards reducing
e Practice to the Simplicity of the Theory ; for
at leaſt two Thirds of the Motion of the Bal-
nce was *now* the Effect of this new applied Spring,
hich is perfectly ſimple, ſo there remained but
e Third of its Motion to be effected by the
her compounded irregular Force, and conſe-
uently the Irregularity of *that* Force could pro-
uce but one Third of the Error that it did when
e whole Motion of the Ballance was the Effect
that unequal Force: and this Experience con-
rmed. The concluſion I would draw from what
have ſaid above is, that as the Force derived to
e Ballance from the Main-Spring through a Train
Wheels, is neceſſarily unequal and irregular, and
is impoſſible entirely to throw off its Agency ;
we can do to improve the Regularity of Watches,
to give the Ballance as great a Quantity of Mo-
on as poſſible in Proportion to *this* Force ; for
hatever Motion it has over and above what is
oduced by *this* Force, is the Effect of the Pen-
ulum-Spring which is perfectly ſimple, and is
a Ballance what Gravity is to a Pendulum, and,
think, would not be improperly called, the artifi-
al Gravitation of the Ballance. This I verily
elieve to be the only rational Scheme for im-
roving Time-Keepers from which we may hope
ucceſs: nevertheleſs, this muſt be ſubject to ſuch
Limitations, as the Purpoſes, for which the Machine
deſigned, require: which I come next to con-
der.

In Pocket-Watches we are limited within very narrow Bounds; for the Force ariſing from the Main-Spring muſt always bear ſo great a Proportion to the Force of the Pendulum-Spring, as to be able to ſet the Ballance in Motion when at Reſt, otherwiſe it will frequently be liable to ſtop, (from the Motion to which the Machine is ſubject deſtroying the Motion of the Ballance) which is by no Means to be permitted. However, ſome conſiderable Improvements (I am ſatisfied) have been made, (reducible to the above Scheme of giving the Ballance as great a Quantity of Motion as poſſible, in Proportion to the Force of the Main-Spring, or rather its Influence on the Ballance) and I make no Doubt but more may and will be; but ſtill the Limitation above mentioned will be an Obſtacle that cannot, I believe, be eaſily got over, and that we ſhall never be able to give them that Degree of Accuracy that one would wiſh for particular Purpoſes, eſpecially that of aſcertaining the Longitude at Sea.

I come now to conſider the Limitations to which Watches for that particular Purpoſe muſt be confined, ſtill going on the ſame Scheme of Improvement, that of giving the Ballance as great a Quantity of Motion as poſſible, in Proportion to the Influence of the Main-Spring upon it. And here it muſt be obſerved, that as there is no Danger, that the Motion which the Watch receives from the Ship ſhould ever take from the Ballance its whole relative Motion, the Office of the Main-Spring will become ſomewhat different from what it was in a Pocket-Watch; in the latter it is neceſſary that it ſhould be able to create a Motion in the Ballance when at Reſt; in the former, all its Buſineſs is to continue a Motion once given to it by ſome external Agent. A ſimple Ballance with its Pendulum-Spring, will, when ſet in Motion, continue ſo for a conſiderable Time, loſing ſomewhat of the Arc it vibrates, every Vibration, till it entirely ſtops; the Buſineſs then of the auxiliary Force of the Main-Spring is only to ſupply this Loſs of Motion, and the leſs of this auxiliary Force is made Uſe of, the more ſimple the Watch will be, and conſequently the greater Accuracy may be expected from it. But ſomewhat more Force will be neceſſary, than would be barely ſufficient to continue this Motion, if the Watch was *fixed* immoveably; for when fixed to a Ship, it will partake of all the Motions of the Ship, and will therefore limit us within narrower Bounds. In order to eſtimate, in ſome Meaſure, what thoſe Bounds are, we will ſuppoſe that the mean Vibration of the Ballance is 180 Degrees, and that there are five Vibrations in a Second of Time. I will ſuppoſe too, that the Ballance vibrates in the Plane of the Horizon (and there are many and ſtrong Reaſons why that Poſition is preferable to any other): the Motion of the Watch, derived from the Ship, cannot affect the relative Motion of the Ballance, but as it is in the ſame, or an oppoſite Direction to it, or partakes of ſuch a Direction; and as the Ballance is ſuppoſed to move circularly in the Plane of the Horizon, it is a circular Motion of the Ship in the ſame Plane only that can in any wiſe affect its Motion. Now I will ſuppoſe, that in tacking about, in a briſk Gale, the circular Motion of the Ship in the Plane of the Horizon is the quickeſt; and I will ſuppoſe too, (but it is only Suppoſition) that the greateſt Velocity of the Ship under ſuch Circumſtances amounts to 90 De-

grees

grees in a Second*; the Ballance, as ſaid above, vibrates 180 Degrees and five times in a Second, and conſequently ten times quicker than the Ship moves; the abſolute Motion of the Ship then can take from or add to the relative Motion of the Ballance but one Tenth of its mean Vibration, or 18 Degrees; its mean Vibrations, therefore, muſt neceſſarily be more than 18 Degrees greater than is ſufficient to its Scaping *(a)*, otherwiſe it would be liable to ſtop; it muſt alſo admit of a Vibration more than 18 Degrees greater than its mean Vibration before it hits the Banking *(b)*, otherwiſe, by frequently hitting it, an Irregularity would be introduced in its Motion. Theſe are the Limits to which, upon the above Suppoſition, we are confined. I call it a Confinement, becauſe I ſuppoſe, that the leſs Space the Ballance moves beyond the Arc that is neceſſary to its Scaping, the greater Quantity of Motion can be procured by the ſame Force from the Main-Spring †; and conſequently a greater

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(a) By *Scaping* is meant the Arc that the Ballance muſt neceſſarily move in order to the Wheels going forward.

(b) By *Banking* is meant Stops to prevent the Machine receiving any Injury from the Ballance moving too great an Arc.

[*] It matters not, whether the Suppoſition is near the Truth or not, whether it is 90 Degrees in a Second, or in a Minute, or ſeveral Minutes; the Reaſoning will be the ſame, but the neceſſary Limits different.

[†] The Force of the Spring is communicated to the Ballance through the Agency of Wheels; theſe have Friction, and a Vis Inertiæ, which will employ ſome Portion of the Force of the Spring to overcome; ſo much as they employ will be taken from the Impulſe the Spring would otherwiſe give to the Ballance; that Portion will be more or leſs, as the Wheels are obliged to move quicker or ſlower, to give that Impulſe; when the Arc it ſcapes is ſmall, in Proportion to the whole Arc it vibrates, it does its Office of impelling the Ballance

a greater Degree of Perfection may be expected where the Machine is fixed immoveably, than where it is ſubject to the Agitations it muſt neceſſarily be in a Ship. It appears then from what has been ſaid, that the greateſt Arc the Ballance vibrates (admitting theſe Numbers) will be about 200 Degrees, and the leaſt about 160, and between theſe two Arcs it will be continually fluctuating, more or leſs, as the Ship has more or leſs of that Motion which only can affect the Motion of the Ballance. We are to conſider then, whether this Fluctuating between greater or leſs Vibrations, will affect the Equality of its Time: I ſuppoſe but very little, if at all; for a ſimple Ballance, as actuated by its Pendulum-Spring only, will, from phyſical Principles, vibrate all Arcs, whether greater or leſs, in the ſame Time. If abſolutely ſo, (which I a little doubt) Care ſhould be taken to apply the auxiliary Force in ſuch a Manner as not to deſtroy this Property; if not abſolutely ſo, it ſhould be applied in ſuch a Manner

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Ballance in a ſhorter Time, than when the Arc it ſcapes is large, and conſequently more of the Force is ſpent upon giving Motion to the Wheels; but that is not all, for when the Ballance is not aſſiſted by the Wheels, it is obſtructed; by the Momentum it has acquired, it carries the Wheels backwards, and is to overcome not only the Force of the Spring, but the Force of the Spring added to the Friction and Vis Inertiæ; and that will be a larger Portion of the whole Arc it vibrates, when it ſcapes a ſmall than when it ſcapes a larger Arc. Theſe are the Reaſons why it appears to me neceſſary that the Arc it ſcapes ſhould be large: I don't ſay how large, that I leave to be determined by Experiment, there being no other Teſt that I know of the juſt Effect of Friction. From hence I ſuppoſe, that if the auxiliary Force acting on the Ballance, was a pure Vis viva (if I may ſo call it) or active Principle, it would be of no Conſequence whether the Arc it ſcaped were large or ſmall, and that it would in either Caſe produce the ſame Velocity in the Ballance.

ner as to help it. I have ſuppoſed above, that the Ballance vibrates 180 Degrees and five times in a Second; but if it were to vibrate but four times in a Second, and its mean Arc 225 Degrees, the abſolute Motion would bear the ſame Proportion to the relative that it did before, and would be ſubject to the ſame Limits. The quicker the Vibration therefore, and the greater the Arc it vibrates, the greater is the Diſproportion between the abſolute and relative Motions, and the greater Quantity of Motion can be had, in Proportion to the Force of the Main-Spring. But this too has its Limits; for, from what has been ſaid, the larger the Arc the Ballance vibrates, the larger Arc it ought to ſcape; and that cannot be encreaſed at Pleaſure without running into Inconveniencies, and introducing greater Errors than we aim at avoiding *, Nor can the Number of Vibrations in a given Time be encreaſed with Succeſs beyond certain Bounds; for it is eaſy to imagine ſuch a Number of Vibrations in a Second as will make it neceſſary to give ſo great a Velocity to the Wheel that communicates the Force of the Main-Spring to the Ballance, that its Inertia, added to the encreaſed Friction, will employ the whole Force of the Spring, and conſequently, inſtead of the Force that is calculated to arrive at the Ballance, none at all will arrive at it. For theſe Reaſons I have above ſuppoſed the Arc to be 180 Degrees at a mean (poſſibly

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* There has been no Method of communicating the Force of the Spring to the Ballance hitherto practiſed in ſmall Machines, that is not attended with Friction; now it may ſo happen (and in Fact does), that when the Arc it ſcapes is enlarged beyond a given one, the Friction may encreaſe ſo faſt, in Proportion to the Influence of the Force acquired by that Encreaſe of the Arc, as entirely to defeat the Deſign of it.

(poſſibly it may bear ſomewhat a greater Arc, for I have made no Experiments to aſcertain it, nor indeed do I think any great Accuracy neceſſary), and the Number of Vibrations in a Second to be five, which at preſent appears to me to be moſt eligible.

By theſe Means, I apprehend, the ill Conſequence of the Inequalities of the Force derived to the Ballance from the Main-Spring through a Train of Wheels may be beſt provided againſt. But as what is aimed at is to make the Machine as perfect as may be; to contribute towards that End, we ought (where it can be done) to make that Force as equal as poſſible; and it may be made much more equal by making the Main-Spring do the ſame Office to a weaker Spring, at ſhort Intervals of Time, that the Hand does to the Main-Spring once in twenty-four Hours, by which all the Friction, and every other Inequality between the Main-Spring and the other weaker one, will become of no Conſequence; and all the Inequalities from the auxiliary Force that can poſſibly affect the Ballance, will be thoſe only that are derived from the ſmaller Spring, and will be run through in ſhort-ſtated Intervals of Time, ſo ſhort as to occaſion no Error that can be perceived before the ſame Inequalities begin again.

Hitherto I have gone on a Suppoſition, that the Force of the Pendulum-Spring (which is ſimple) is perfectly uniform and equal to itſelf at all Times; but we find by Experience it is not ſo, but that it ſuffers a conſiderable Alteration in its Force from Heat and Cold, Heat taking from and Cold adding to its Elaſticity, and to ſo great a Degree as to make a Difference in Time of no leſs than ſix Minutes between a hot Summer's Day, and a cold Winter's Day; this therefore muſt be provided againſt. It is well known by Experiments made by many ingenious Men, that all Metals expand and contract by Heat and Cold, and that the Alteration they ſuffer is in different Proportions. Mr. GRAHAM, as far as I can learn, was the firſt that ever thought of applying this Difference in the Expanſion and Contraction of different Metals to remedy the Evil ariſing to Time-Keepers from Heat and Cold, by conſtructing the two Metals (Braſs and Steel) in ſuch a Manner as to procure a very ſenſible Motion (indeed to any Degree required), and as this Motion is the Effect of the ſame Cauſe that produces this Error we are now conſidering, it may be made to counteract it. Whether Mr. GRAHAM ever carried his Thoughts on that Subject into Execution, or not, I cannot tell; but Mr. Harriſon, who alſo hit on the ſame Thought, has, by executing it to a very great Degree of Accuracy, ſhewn it to be practicable.

Thus have I given, according to my preſent Apprehenſions, the cleareſt Reaſonings upon the Means of improving Time-Keepers (with a Ballance) as far as I think they will admit of Improvement. Whether what I have wrote is intelligible or not, I cannot tell; for writing is not my Province, and indeed I am happy that it is not, I ſhall ſum up the whole in *ſhort* that I have above ſuppoſed to be neceſſary to the Improvement of Watches for the Uſe of the Sea.

The Ballance ſhould vibrate in the Plane of the Horizon, as in that Situation it will admit of ſmaller Pivots, with Safety from the Shocks of the Ship, and conſequently leſs Friction (for I have not ſuppoſed the Friction taken off by any other Means), and the wearing that is the Conſequence of the Friction (for ſome wearing there will be) will be leſs liable to deſtroy the Equilibrium of the Ballance; in that Situation alſo, I apprehend, the Motion of the Ballance will be leaſt diſturbed by he Motion of the Ship. The Ballance ſhould by no Means be made of Steel, or Iron, as thoſe Metals are ſubject to Magnetiſm.

The Vibrations ſhould be quick, and the Arc arge, that the Velocity of the Ballance may be as great as poſſible, with any Convenience, in Proportion to the Velocity with which the Ship moves circularly.

The Motion of the Ballance in this Arc is to be ept up with the leaſt Force that is poſſible, ſo as o admit of its loſing ſo much of its Arc, as it is iable to loſe (by the Motion of the Ship) without Poſſibility of its ſtopping. That is, in other Words, the Quantity of Motion in the Ballance hould be as great as poſſible, in Proportion to the nfluence of the auxiliary Force, or the Force derived to it from the Main-Spring.

The Force derived from the Main-Spring, ſhould e made as equal as poſſible, by making the Main-Spring wind up another ſmaller Spring at a leſs Diſtance from the Ballance, at ſhort-ſtated Intervals f Time. I think it would not be impracticable o make it wind up every Vibration ſmall Springs milar to the Pendulum-Spring, that ſhould immediately act on the Ballance, by which the whole orce acting on the Ballance, would be reduced to he greateſt Simplicity, with this Advantage, that he Force would encreaſe in Proportion to the Arc.

There ſhould be a Proviſion made againſt Heat nd Cold (Means of doing which are well known), but it ſhould be abſolutely without Friction, wher it is in Contact with the Pendulum-Spring part cularly.

I think the Diameter of the Ballance ſhould be ſome certain Proportion to its Weight*. What, have not made any Experiments to aſcertain, an I believe it cannot be come at any other Way but a very few ſimple Experiments would eaſily determine it.

The Watch ſhould go while winding up.

The Whole ſhould be made of Materials th leaſt liable to Injury, eſpecially thoſe Parts ſubje to wear, and where the Friction is of moſt Conſ quence. If Oil ſhould be neceſſary (and I fear will), ſome Errors will ariſe from its different Sta at different Times.

I think, there is no Neceſſity to ſay, that eve Part ought to be well executed.

June 25, 1763.

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* There are two principal Obſtructions to the Motion o Ballance, Air and Friction; the Quantity of Motion in Ballance being ſuppoſed determined, it may be effected by greater Diameter and leſs Weight, or a greater Weight leſs Diameter. In the firſt Caſe, the Reſiſtance from the will be encreaſed; in the latter, the Friction. The Buſineſ to divide it between them ſo as ſhall be moſt conducive to Perfection of the Machine under all the different Circumſta it is liable to; which I know no Method of coming at bu Experiment, and by that Means, I believe, it may pr eaſily. There ſeems to be theſe Reaſons for leaning ſtron towards the Reſiſtance ariſing from the Air, that, though Denſity is fluctuating, the Limits are known, and the Mea nearly alike one Year with another; beſides that the Reſiſta from it is the ſame in all Poſitions of the Watch: but the ſiſtance that is the Conſequence of Friction, is very differen different Poſitions of the Watch; it is alſo an encreaſing ſiſtance, to what Degree, Obſervation only can aſcertain; likewiſe liable to frequent Variations from Cauſes that we but barely gueſs at.

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